Motion Simulator for an Underwater Glider for Long-term Virtual Mooring Including Real Devices in Loop

Kenichi Asakawa
Marine Technology and Engineering Center
JAMSTEC
Yokosuka-shi, Kanagawa, Japan
asakawa@jamstec.go.jp

Keisuke Watari
Marine Technology and Engineering Center
JAMSTEC
Yokosuka-shi, Kanagawa, Japan

Masahiko Nakamura
Research Institute for Applied Mechanics
Kyushu University
Kasuga, Fukuoka, Japan

Tadahiro Hyakudome
Marine Technology and Engineering Center
JAMSTEC
Yokosuka-shi, Kanagawa, Japan

Junichi Kojima
KDDI R&D Laboratories Inc.
Fujimino, Saitama, Japan

***Abstract*— We present an outline of a motion simulator for the prototype underwater glider "Tsukuyomi". The project goal is the development of an underwater glider for long-term virtual mooring. When developing control software and debugging it, a motion simulator of the glider is necessary to confirm the software reliability and to improve the development efficiency. The main part of the motion simulator is installed in a PC and communicates with the Tsukuyomi central computer via LAN. It receives the glider status and simulates the dynamic motion of the glider. Then it returns the simulated result including updated depth, pitching and heading to the main controller. Consequently, it provides a virtual environment in which the glider operates.**

Keywords—underwater glider, simulation, motion simulator, Tsukuyomi, virtual mooring

I. INTRODUCTION

The ocean has played an important role in stabilizing the global climate. Its heat capacity is thousands times greater than that of the atmosphere. Nevertheless, a rise in temperature, even in oceans deeper than 2,000 m where the temperature should be stable, has been reported. Because of its greater heat capacity, even a small rise in the temperature of the deep ocean would have a great effect on global warming. We must monitor and elucidate the ocean status to understand the characteristics of the global climate change correctly.

Ocean environments have been monitored using many methods including profiling floats, mooring systems, ships, and satellites. However, because of its immense area and vast volume of water, it is difficult to gather sufficient data even when using all of these methods. It is also difficult to monitor environmental variation in water that is deeper than 2,000 m with a moderate cost over a long time.

In next-generation ocean observation systems, to gather data efficiently with limited resources, key areas where environmental variation appears in the early stage should be selected, and observations should emphasize these waters. Observations should be extended to waters deeper than 2,000 m. Underwater gliders for virtual mooring will provide a unique means to achieve those goals.

After proposing a new kind of underwater glider for long-term virtual mooring, we developed a prototype named "Tsukuyomi". It can glide under the sea as ordinary underwater gliders can do. In addition, it will be able to settle to the seafloor and sleep there. It will wake up periodically to ascend and descend between the sea-floor and the sea-surface monitoring the sea environment. It will locate its position while floating on the sea-surface using GPS, and will send data via Iridium. If it drifts a long distance, then it will glide to the designated area. Consequently, it can conduct long-term monitoring from the sea surface to the seafloor, staying in a designated water area. The objective and background of this project were presented in an earlier report [1]. We conducted the first sea test in 2012 [2].

Reliability of the software of gliders is extremely important. If the control software were to hang up when Tsukuyomi is operating underwater, it would be lost. However, it is very difficult to operate the control software in a realistic environment for debugging purposes. To make it possible to run the software in the virtual environment for debugging, we have developed a motion simulator.

The main part of the motion simulator, a dynamic motion simulator (DMS), is installed in a personal computer (PC). It communicates with the main controller of Tsukuyomi via LAN. The dynamic motion simulator receives the status of the glider and simulates the glider's dynamic motion. Then it returns a simulated result including depth, pitch, and heading to the controller. The main controller controls Tsukuyomi based on the returned information from the DMS. Consequently, the motion simulator provides a virtual environment in which the glider operates.

II. OUTLINE OF TSUKUYOMI

Fig. 1 shows a photo of Tsukuyomi. The maximum water depth, the weight in air, and the length are, respectively, about 3,000 m, 150 kg, and 2,500 mm. Its general arrangement, the electrical system, and other specifications are described in the literature [1], [2].

III. MOTION SIMULATOR

Fig. 2 shows a block diagram of the motion simulator. It consists of several sub-systems including the DMS, device simulators (buoyancy engine (BE) simulator, gravity-center controller (GCC) simulator, iridium simulator and GPS simulator) and a graphical user interface (GUI). The DMS and the GUI are installed in a PC, and others are installed in the Tsukuyomi central computer. We use Armadillo-440 as the central computer. The operation system is uLinux. These two computers are mutually connected via LAN. The main controller of Tsukuyomi and the main controller of the

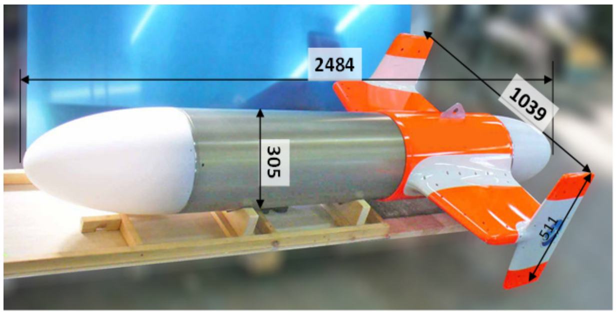

Fig. 1 Photograph of Tsukuyomi.

Table 1 Initial Conditions sent to PC

Position (X,Y,Z)
Velocity (u, v, w)
Angle (ϕ, θ, ψ)
Angular velocity (p, q, r)
Gravity center (x_G, y_G)
Buoyancy center x_B
Weigh of moving portion of GCC
Volume of the glider
Mass of the glider
z_G-z_B
Coefficient between the amount of oil movement and change of x_G
Coefficient between the rotation of GCC and change of y_G
Volume elasticity of water and the glider

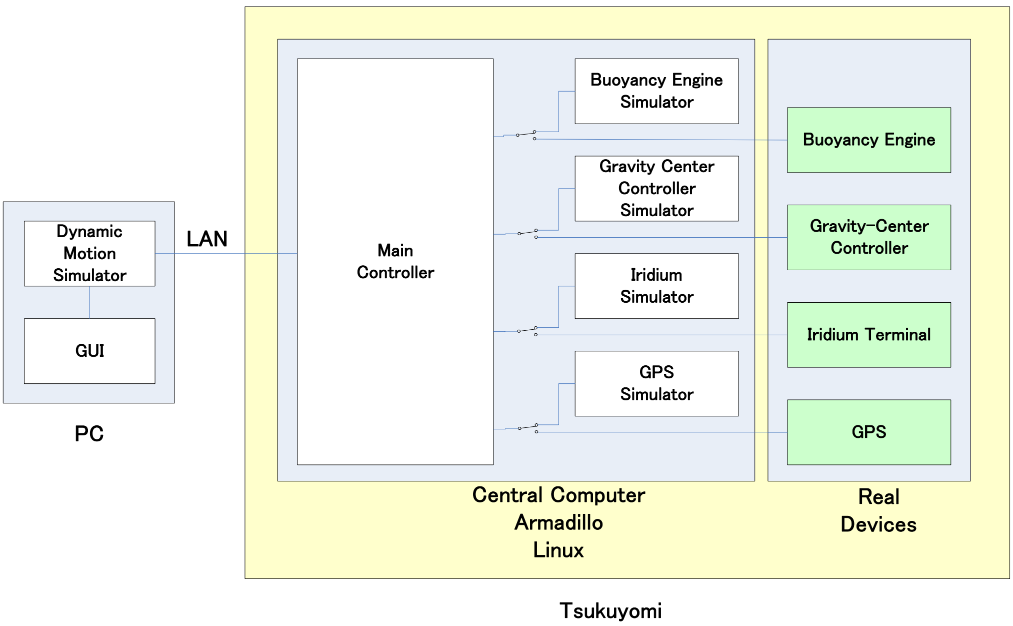

Fig. 2 Block diagram of the motion simulator.

$$
\begin{bmatrix}
m+A_{11} & 0 & 0 & 0 & mz_G & -my_G \\
0 & m+A_{22} & 0 & -mz_G & 0 & mx_G+A_{26} \\
0 & 0 & m+A_{33} & my_G & -mx_G+A_{35} & 0 \\
0 & -mz_G & my_G & I_{xx}+A_{44} & 0 & 0 \\
mz_G & 0 & -mx_G+A_{53} & 0 & I_{yy}+A_{55} & 0 \\
-my_G & mx_G+A_{62} & 0 & 0 & 0 & I_{zz}+A_{66}
\end{bmatrix}
\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \\ \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix}
=
\begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix}
\tag{1}
$$

Fig. 3 GUI of the DMS

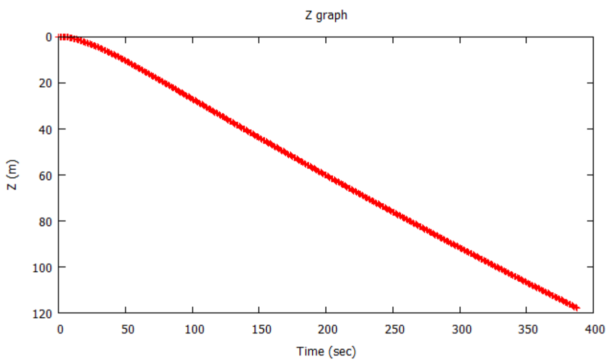

Fig. 4 Example of the simulation results

simulator are the same. Only input–output ports differ from each other.

The initial conditions of the simulation shown in Table 1 are provided in a text file in the central computer. These parameters are sent to the DMS at the first stage. Then the DMS starts to simulate the glider motion using equation (1) [3]. The definitions of variables are described in an earlier report [3].

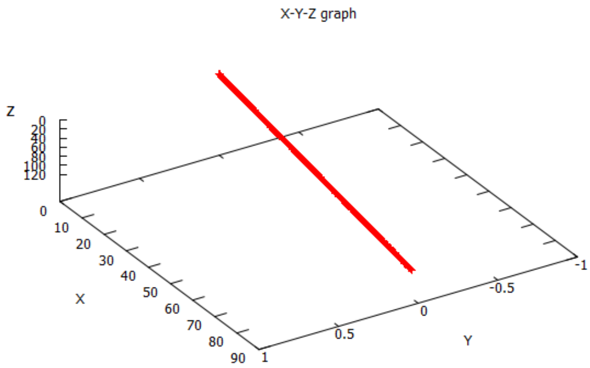

Fig. 5 Example of the simulated footprint

The DMS receives status information for the position of GCC and oil amount in the oil-reservoir of BE from the main controller. Then it simulates the vehicle movement and returns the updated x-y-z position, angles of the vehicle, velocity, and angular velocity to the main controller. The main controller uses the values returned from DMS instead of data obtained from sensors such as a depth meter, magnetic compass, and tilt-meter. The main controller then sends a control command to the BE, GCC, and other devices according to the pre-determined sequence. It can control real devices in the simulation. These devices can be replaced by each device simulator if they devices are not available. These device simulators include the BE simulator, the GCC simulator, the Iridium simulator and GPS simulator. These device simulators receive commands from the main controller and return the operation results to the main controller. Using real devices, the vehicle motion can be simulated more precisely.

The seawater density increases with depth. The glider volume also changes with depth because of the water pressure, which means that the glider buoyancy changes with depth. We have implemented a function to incorporate these effects into simulation. This motion simulator provides an environment that resembles the real underwater environment.

Fig. 3 shows the GUI of the DMS. The glider status, including its position, angle, velocity, angular velocity, volume change, and position of GCC are displayed numerically when simulating the motion. We can display the simulated time series change of these parameters by clicking buttons on the display. Figure 4 presents an example of the simulated time series display. We can also display the simulated three-dimensional footprint of the glider, as presented in Fig. 5.

IV. Conclusion

Using the developed motion simulator, debugging of the control software becomes easier. It becomes possible to develop reliable software. Moreover, we can estimate suitable control parameters for heading and pitching control using the motion simulator. We will add simulation capability of sea currents and seafloor topography to the motion simulator, which will enable it to simulate long-term monitoring.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number 2424614

References

[1] Kenichi Asakawa, Masahiko Nakamura, Taiyo Kobayashi, Yoshitaka Watanabe, Tadahiro Hyakudome, Yuzuru Ito and Junichi Kojima, " Design Concept of Tsukuyomi – Underwater Glider Prototype for Virtual Mooring –," in Proc. of OCEANS'11 Santander, 2011.

[2] Kenichi Asakawa, Taiyo Kobayashi, Masahiko Nakamura, Yoshitaka Watanabe, Tadahiro Hyakudome, Yuzuru Itoh and Junichi Kojima., "Results of the First Sea-test of Tsukuyomi, a Prototype of Underwater Gliders for Virtual Mooring," in Proc. OCEANS'12 MTS/IEEE Hampton Roads, 2012.

[3] Masahiko Nakamura, Kenichi Asakawa, Tadahiro Hyakudome, Satoru Kishima, Hiroki Matsuoka and Takuya Minami, "Hydrodynamic Coefficients and Motion Simulations of Underwater Glider for Virtual Mooring," IEEE J. of Oceanic Engineering, to be printed.